

A NEW TECHNIQUE FOR TROUBLESHOOTING LARGE CAPACITIVE ENERGY STORAGE BANKS*

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Abstract

Many pulse power systems rely on large numbers of inductively isolated high voltage capacitors configured in parallel for energy storage. Often when an energy storage capacitor fails there is little or no external indication. Identifying the failed component can be a time consuming and potentially hazardous operation. We have developed a new non-invasive (i.e. no dismantling of the bank is required) technique that greatly improves personnel safety as well reducing troubleshooting time. We present the theory of operation, a complete description of the battery-powered hardware, test results and techniques of operation.

I. INTRODUCTION

The Power Conditioning System (PCS) of the National Ignition Facility (NIF) like many pulse power systems relies on large numbers of inductively isolated high voltage capacitors configured in parallel for energy storage. When an energy storage capacitor fails in such a capacitor bank, there is often little or no external indication showing which capacitor failed. Identifying the failed component can be a time consuming and potentially hazardous operation. Conventional methods using capacitance meters require that each capacitor be disconnected and tested independently. We have developed a new non-invasive technique (i.e. no dismantling of the bank is required) that greatly improves personnel safety as well reducing troubleshooting time.

II. THEORY OF OPERATION

A simplified schematic diagram of the National Ignition Facility (NIF) Main Energy Storage Module (MESM) is presented in Figure 1. The actual bank consists of up to 24 capacitors and their attending damping element. Each

individual capacitor can store up to 100kJ. This could of course be any large inductively isolated capacitor bank.

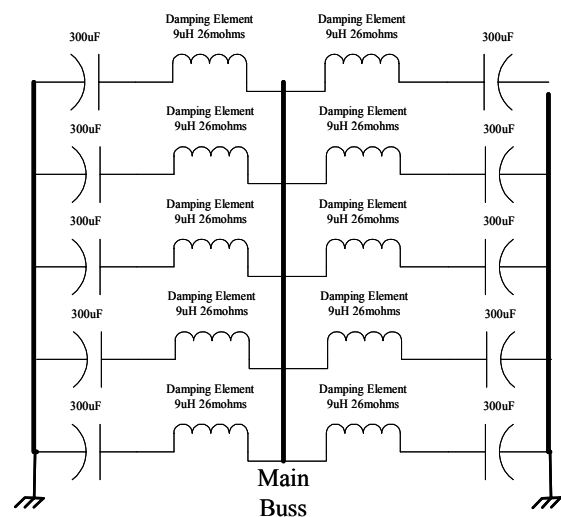


Figure 1. Simplified MESM Diagram

If an AC signal is introduced across any single capacitor the circuit may be re-arranged to produce the equivalent circuit shown in Figure 2.

We are now left with a very simple parallel resonant pair, or in radio terms a "tank" circuit. Recalling basic circuit theory, we recognize that impedance for a parallel LC circuit is highest at the resonant frequency. If we make the source a sweep generator we can find the resonant frequency of our tank circuit by watching for either a peak in the voltage across the capacitor or a null in the current supplied by the generator. In the case of the NIF bank the resonant frequency turns out to be very close to 3kHz. All of the individual circuits (capacitors) should look pretty much the same with the exception of the circuit with the bad capacitor, which will either not resonate at all (most

* This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48

** The Titan Corporation acquired the pulsed power portion of Maxwell Physics International Company in March, 2001, after the completion of the project described in this paper

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE JUN 2001		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE A New Technique For Troubleshooting Large Capacitive Energy Storage Banks				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Lawrence Livermore National Laboratory 7000 East Ave. Livermore, CA 94551-0808				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. IEEE International Pulsed Power Conference (19th). Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.					
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15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 3	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

likely) or will resonate at a significantly different frequency from the rest.

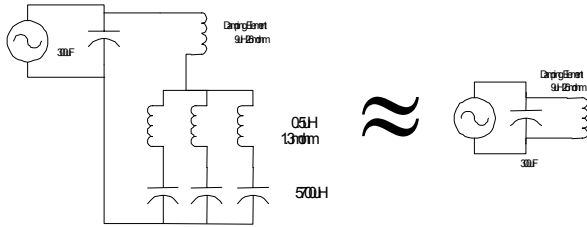


Figure 2. Equivalent Circuit

III. DESCRIPTION OF HARDWARE

The equipment is battery powered and is not referenced to building ground, providing an extra measure of safety for personnel and equipment. Initial proof-of-principle tests were done with AC powered equipment with known good capacitors to which small additional capacitors were added or taken away.

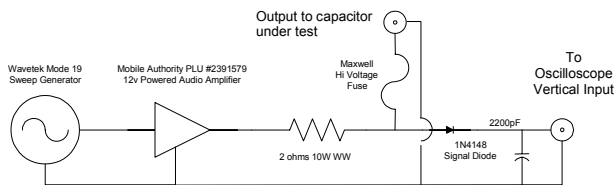


Figure 3. Basic Circuit Diagram

The basic circuit diagram of the tester is shown Figure 3. The sweep generator is an AC powered unit but requires only a few watts. Power for this unit was provided by an inexpensive 12VDC to 120VAC inverter. The amplifier was required to improve the signal to noise ratio. The impedance of the circuit at resonance is less than one ohm. As noted above the primary frequency for the NIF is 3kHz very conveniently located in the audio band. An automotive stereo amplifier was selected as battery powered, robust and inexpensive. The two-ohm series resistor provides a stable load for the amplifier. The output of the amplifier is coupled through a large high voltage fuse. Connection to the capacitor under test is through a length of RG-58 co-axial cable mounted to the end of 8-foot insulating pole. The signal diode and capacitor form a simple Amplitude Modulated (AM) detector for ease of display and interpretation. A battery powered digital oscilloscope rounds out the system.

IV. TEST RESULTS

Two oscilloscope traces from actual capacitor measurements in a NIF MESM are shown to the right. The Figure 4 shows the response of a normal NIF capacitor/damping element pair. Note that the resonant frequency is slightly above 3kHz, as the hand calculation would predict. The Figure 5 shows a different capacitor (200µF) with the same inductor. The resonant frequency has shifted to about 3.7kHz as expected. Changes as small

as 30µF can be easily detected (tested by adding and removing a 30µF capacitor in parallel with the unit under test.) However the differences in inductance of the ground return for each capacitor can also account for this much

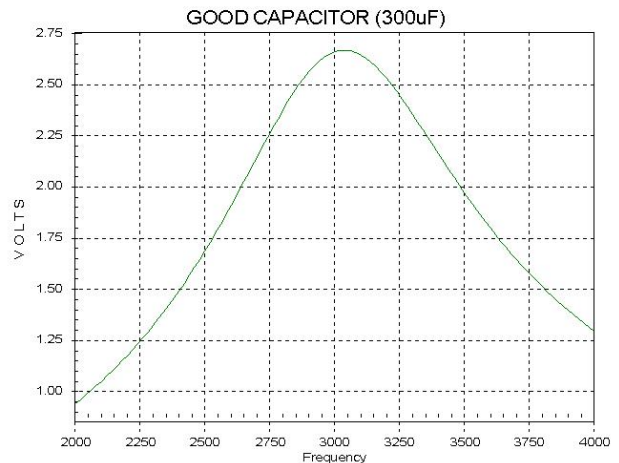


Figure 4. Normal Capacitor

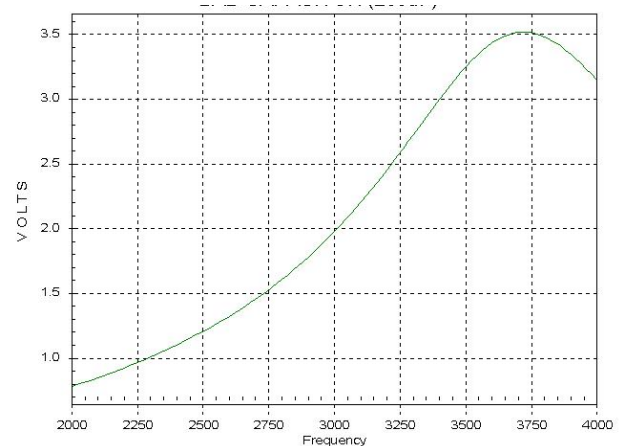


Figure 3. Defective Capacitor

variation. To reliably detect such small changes, the return lead of the probe must always be connected to the same point on the module frame and the data compared to measurements made when the bank is in a known good condition.

V. TECHNIQUES OF OPERATION

All normal precautions for dealing with a potentially lethal capacitor bank must first be observed. The bank must be discharged and checked for any dielectric memory voltage. The central bus should be grounded for additional electrical safety, but this is not required for the operation of the equipment. A small low voltage/low current "reference pair" of a 300µF capacitor and a 9µH inductor is placed across the output leads of the test probe. The start frequency of the sweep generator is set to 2kHz, the stop to 4kHz. The sweep rate is adjusted until a signal

sweep just fills the screen. Similarly, the vertical scale of the oscilloscope is adjusted to provide a full-screen signal. The reference pair is removed and the return lead of the probe is attached to the can of the capacitor under test. The test probe is applied to the junction of the capacitor and it's associated inductor. The resonant frequency is noted and compared to other capacitors in the bank.

A flat line at the bottom of the trace indicates a shorted capacitor, no trace (voltage off scale high) indicates an open. Resonant frequencies above 3kHz indicate a partial loss of capacitance in the unit under test. Frequencies below 3kHz indicate a very unlikely increase in capacitance; if this occurs, the tester should again be tested against the reference pair to confirm proper operation.

VI. FUTURE PLANS

One disadvantage of the current system is that physical contact must still be made to inject the signal into the junction of the inductor and capacitor. One proposed improvement is to drive a coil with the output of the amplifier and inductively couple the signal via transformer action into the damping element of the capacitor under test. In effect we would build a 3kHz "Grid Dip Meter" another piece of technology borrowed from the RF world.

Using a laptop computer to replace both the sweep generator and the oscilloscope will enhance the whole system. A PCMCIA data acquisition card will provide both D/A and A/D functions. The D/A function will create the sweep frequency signal that will still be fed to the amplifier. The A/D section will record the voltage at each frequency. There are many advantages to this approach: A laptop computer is less expensive than an oscilloscope. It is inherently battery powered. The sweep signal generator and its DC/DC inverter are eliminated. The system will be more compact and transportable. Finally, record keeping will be simplified. The characteristic resonance for each capacitor/inductor pair could be quickly measured and stored in a spreadsheet or database. In the event of failure, overlaying the original data with the current measurement can provide an easy and quick go/no go test.